EVALUATION OF ULTRA-HIGH-SPEED FIRE PROTECTION SYSTEMS PRESENTLY IN SERVICE AT ARMY AMMUNITION PLANTS

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EXECUTIVE SUMMARY

A brief study was made of current fire protection systems employed in Army ammunition/propellant-related facilities and their abilities to meet fire protection performance requirements to minimize loss of life, financial loss, and downtime of fire protection systems and production lines. The study included (1) reliability to detect/suppress events, and (2) immunity to false alarms from nonfire objects and phenomena.

It was found that current fire detection and suppression technologies being applied in these facilities are, in general, not adequate and should be thoroughly reviewed with respect to the threat, required reliability, desired performance criteria, and overall mission success goals. Moreover, the fire/explosion threat needs to be defined in terms of the system performance requirements. Detailed performance specifications are needed and should be included in each and every purchase description/RFP. It was also apparent from the study that formal guidance is lacking for Hazard Class 1.3 protective features.

A review of past test results substantiated the need for faster and more reliable fire detection and suppression approaches. Current installed systems are, in general, not satisfactory for most types of pyrotechnic fire events. They lack the necessary speed, effectiveness, and reliability. False alarms/accidental releases of fire suppressant continue to occur, although records of their occurrences are either sparse or do not adequately describe their causes.

A major observation was that there is a lack of scientific data pertaining to the nature and properties of the fire/explosion events themselves, especially their radiant spectral emissions.

The study concluded with the recommendation that various types of fire detection and suppression systems should be field-tested to determine the optimum configuration for each major application. However, before the detection part of such systems can be adequately tested it is necessary to know the spectral irradiances from each type of pyrotechnic material fire. Without these data it is impossible to select with any scientific foundation the appropriate fire/explosion detection spectral bands. Setting a pyrotechnic fire and testing the responses of commercial UV and IR detectors that are designed for hydrocarbon fire detection will lead to erroneous conclusions.

A final recommendation was to test new technologies for these applications, such as machine vision fire detection, as well as to determine approaches to modify and update in-place fire protection systems to optimize their performance and reliability.

SECTION I

INTRODUCTION

A. OBJECTIVE

The objective of the study was to analyze the capabilities of existing ultra-high-speed fire protection systems installed in Army ammunition plants. In meeting this objective, a brief feasibility analysis was required to determine whether or not the state of the art in current ultra-high-speed deluge fire protection systems could be improved, if needed, by incorporating such advanced technologies as machine vision fire detection and advanced fire suppression concepts being developed for other applications.

B. BACKGROUND

In general, the technology of fire detection and suppression, in use in some Army ammunition plants, has not fully kept up with advancements in new technologies for fire detection and suppression. It was found that, in general, new technology was not incorporated into those systems that have been modified (e.g. nozzle locations, piping configuration, water pressure, etc.). A major observation was that considerable improvements in detection time, false alarm reduction, and suppression time and efficiency could be attained by optimizing currently installed systems and adding new-technology hardware.

False alarms have occurred, but the causes have not been determined to any major degree. A survey of facilities to determine what nonfire radiation sources are present and what is their spectral emission features would be a major step forward in improving the overall performance of fire protection systems in general.

Time of response of existing detectors is evidently not consistent and may vary over a large range. Reasons for this non- consistency should be determined.

C. SCOPE

The study was aimed at evaluating current and past performance of installed fire protection systems. Evaluations were made to determine and recommend possible modifications, technology improvements, and tests which could better satisfy the performance requirements for the specific application.

It was determined that field tests are necessary, as well as measurements of the spectral irradiances of pyrotechnics and propellant material fires/explosions. Detectors are being employed whose wavelengths may or may not be in consorts with the actual emission bands of the fires they are to detect. These emission characteristics must be known to optimize response time of detection; they must also be known in conjunction with those from nonpyrotechnic material fire sources, false alarm sources, such as lights, tools, phenomena, objects, etc. that may exist in the vicinity of the detectors.

It was concluded from the study that there has been a lack of investment in R&D related to the problems of pyrotechnic fire detection, fire suppression, system performance, and overall system reliability.

SECTION II

EVALUATION OF ULTRA-HIGH-SPEED DELUGE SYSTEMS

A. INTRODUCTION

One of the most obvious problems with existing ultra-high- speed deluge systems is the lack of attention to, or lack of knowledge about, the processes, product and operations present at the facility. No discussion of fire suppression systems in high energy chemical facilities is complete without discussion about the product and process involved. (Discussion of fire detection follows in Section III.)

B. ACTIVE FIRE PROTECTION

Ultra-high-speed deluge systems are common in government and military facilities that process explosives, pyrotechnics and propellants, and munitions. Presently the definition of an ultra-high-speed deluge system is a system that has a reaction time of 100 milliseconds or less. ("Reaction time" is defined here as the time from fire "detection" to the suppressant reaching the nozzle.) While this is the accepted standard for ultra high speed detector reaction, this is not an accurate definition for both reaction of the detector and suppression system. These systems utilize optical fire detection that allows for fast detection of flash or flame. In most cases, ultra-high-speed deluge can suppress a fire before it reaches dangerous proportions or possible detonation (in the case of high explosives).

The speed necessary to halt a pyrotechnic or propellant fire is dependent on many variables including the type of process (whether it is an enclosed vessel, an extrusion process, mixing, drying, pressing, etc.) and the proximity of the personnel and critical equipment. Sometimes the only alternative or option is to allow it to burn. Conversely, there are instances in which ultra-high-speed deluge is necessary to save lives and protect costly equipment.

With the many varieties of chemical fire suppressants available today, one may wonder why water is used for high energy chemical mixtures, explosives, pyrotechnics, etc. Almost all explosives, propellants, and pyrotechnic mixes contain the necessary oxygen for the burning process. Most high-energy mixtures are a combination of a fuel and an oxidizer. The oxidizers are the nitrate and chlorate families, i.e., potassium nitrate, potassium perchlorate, barium nitrate, potassium chlorate, ammonium nitrate, etc. Because of these oxygen-yielding substances, it is impossible to stop the propellant fire by suppressing the oxygen supply.

Why water? It is generally agreed that cooling is a principal factor because it prevents feedback of sufficient heat energy to maintain combustion. It is desirable to get the water to

the actual burning surface; however, this is not enough, as the fire will burrow into the mixture and continue to burn, being shielded from the water by an outer layer of water soaked material. This makes it highly desirable to be able to apply the water rapidly before burrowing can occur.

Another factor which makes rapid operation essential is that water must reach the burning surface before the pressure of combustion gases is high enough to prevent water from reaching the source of the fire. This requires that the system operate in a matter of milliseconds.

In summary, the basic purpose of the water is to cool down and disperse the explosives or propellant. Applications for ultra-high-speed suppression are as many and as varied as there are high energy products.

Some factors that may influence the speed of deflagration are: mass of the compound; density; temperature; moisture or solvent content; the physical geometric shape or particle size of the compound; and whether or not the substance is contained. A good example of how different containments could affect the burning characteristics of high-energy mixtures is that of black powder. Black powder, one of the oldest and most versatile explosives, when burned in an open long train, is relatively slow burning and is sometimes used to make fuses. Confined in a tube with one end open for exhaust, black powder can be used as a propellant. When confined to a fairly rigid vessel, black powder can become explosive with deflagration speed almost reaching detonation.

C. PRODUCT & PROCESS

"Product" and "process" must be addressed by everyone involved in explosive safety from the project originators to the installing contractor.

Products encountered in high-energy chemical facilities can be quite varied and must be considered since the hazards associated with the individual products differ. An equally important consideration is that the hazard presented by an individual product may vary during the manufacturing of the product.

Risk can be managed by either minimizing the probability of an accident, or by minimizing the consequences of that accident. It is appropriate to look to minimizing both probability and consequence. Generally pyrotechnic accidents are the result of unintentional ignitions and the consequence of an accident is directly related to the amount of material accidentally ignited and the number of persons exposed to the accident. Thus, relative explosive safety can be achieved through a combination of those measures which reduce the chance of accidental ignitions, and when the amount of pyrotechnic materials and the number of people in work areas is kept to a minimum.

In the broadest categorization, high-energy chemical products can be placed into four categories. High explosive, pyrotechnics, propellant, and initiating explosives. Products in

each category have like characteristics of that category but can transcend or overlap to other categories. There are more accurate and better detailed methods of categorization of explosives, such as the U.N. numbering system. For the purpose of this discussion, only the basic four categories will be considered.

1. High Explosives

Examples of high explosives include but are not PETN, RDX, C4, TNT, etc. The first thoughts or reactions to ultra-high-speed deluge protection for high explosives is that there is no fire protection system that could stop the detonation process, when the explosive goes to a high-order state. In many cases, however, there is a fire before the explosion. Examples of high explosives process applications are extrusion dies for C-4 explosives or a TNT melt kettle. In these situations, there is a high probability that there will be a fire preceding the explosion. The fire could start and propagate until the pressure build-up was enough to achieve high-order detonation or a cook-off type of reaction. In this scenario, ultra-high-speed deluge would be feasible in stopping the initial fire which precedes a possible explosion.

2. Pyrotechnics

Items that fall into the pyrotechnic category are flare mixtures, mag-tef flare mix, smoke mixes, first fire, delay mixes, salute mixes, etc. Pyrotechnics cover such vast extremes in characteristics and hazards that one must be careful to study each one individually. (For example, under certain conditions, mag-tef and salute mix, can detonate similar to high explosives.) A few of the processes involved in their manufacture included grinding mixing, activation of binders, extruding, pressing, granulating and drying, these being some of the most common processes encountered.

Fires occur often during cleanup or equipment tear down. This should always be considered when designing an explosive prevention system or ultra-high-speed deluge system so that the system will activate and do its job during the cleanup and tear down process if it is deemed a possible hazard. In most cleanup or repair situations, plant personnel are in the hazard area where explosive residue is present.

3. Propellants

Propellants offer some similarities to hazards explosive and pyrotechnic categories. However some processes are unique to propellant. Propellants are extruded with the same hazards as extruding high explosives, except that propellants will burn much more aggressively, although there is probably not as much of a chance of achieving detonation. A good rule of thumb is to assume that anywhere there is action (movement, friction impact, static discharge) there is a chance for initiation, i.e., where the propellant leaves the extruder die or the extrusions are being cut into pellets during the cutting action. For composite propellant mixing, ultra-high-speed fire protection flooding of the mixing bowl is advised. If using a closed mixer, infrared detection is presently the state-of-the- art method to use in the closed

vessel. It offers faster reaction time and is less subject to blinding or obscuration.

Propellants are often involved during demil (demilitarization) operations. During the demil process, the munitions body is separated or opened so the propellant may be poured into a collection container. The equipment and operator should be protected while the projectile is pulled from the shell or cartridge. Also, during pouring of any propellant, there is a potential hazard because of friction and possible static initiation. There is also a chance that the propellant may have become more sensitive than normal. Large quantities of propellants when contained in hoppers or similar containers should receive deluge water both from above and flooding from within the container as with some of the pyrotechnic mixes.

The progressive burning and increasing burn velocity of propellants emphasizes the need for a fast fire protection system that will extinguish or suppress the flame before it is out of control and the gas velocity is such that it will not allow for water penetration.

Triple base propellant (consisting of nitrocellulose, nitroglycerin and nitroguanidine), double-based propellants (consisting of nitrocellulose and nitroglycerin) and single-base propellants (consisting mainly of nitrocellulose) do not exhibit differences in the ability to be extinguished by water spray, although the burning rates and temperatures vary. More testing would have to be done to verify the affects of the water spray (varying amounts and speed) on the different propellants.

4. Initiating Explosives

Explosives such as mercury fulminate, lead azide, and lead styphinate, pose particular combustion hazards. They are very sensitive to heat, static, friction and impact initiation and seem to transcend the deflagration state and almost evaporate into a detonation.

With these compounds, probably the wisest safety measure would be small batches and isolating the material. Ultra- high-speed deluge for these initiators would probably only be effective as a deterrent to propagation. Avoid using brass fittings and nozzles in lead azide areas as copper and brass; when combined with moisture, they may cause lead azide to form extremely sensitive copper azide.

The preceding was a brief summary of a high-energy process applications where ultra-high-speed deluge may be incorporated. Although, many other substances and processes warrant the use of ultra-high-speed fire protection, this has been a review of some of the more common. Both the product and the process should be reviewed before designing and installing a ultra-high-speed fire protection system. Specifications for the systems should be written for each application. Generic specifications seldom provide an adequate system.

Whenever possible, it is suggested that actual burn tests be performed using the same high-energy substance and the same process situation for the test and design as will be used in the final application.

D. SOURCES OF IGNITION/ENERGY INPUT

Almost all accidental fires or explosions in explosive facilities are due to unwanted energy input externally or internally applied to the product during a certain point in the process.

Energy input occurs in many forms and can be a combination of different sources of energy input. The following is a list of some of the possible sources of energy input:

Static	Thermo-Chemical
Friction	Flame
Impact	Pressure
Heat	Catalytic/Chemical

Every process utilized in the manufacture of high-energy chemical product is a source of energy input. Under normal conditions, it is not a problem. The problems occur when the energy input, or combination of energy input, becomes great enough to cause ignition. Conversely, the product may have been altered or sensitized to a point where normally acceptable energy input can cause ignition. The key to effective fire suppression is to key on the part of the process where the energy input does or can occur.

Common operations used in the manufacturing of explosives and pyrotechnics should be studied as to their potential for energy input. The following list provides some examples:

Grinding	Melt/Pour Liquid
Mix/Blend	Extrusion
Press/Consolidate	Curing
Drying	Mandrel or Core Removal
Addition of Solvents	Clean-Up
Transport	Storage
Pour/Fill Dry	Machining
Cast	Rework

E. COMMON DEFICIENCIES FOUND IN EXISTING DELUGE SYSTEMS

1. Specification

One recurring problem found in existing ultra-high- speed deluge systems can be traced back to the original specification. Very often the specification will be generic, not one that applies specifically. Generic or "nonspecific specifications" render only an ineffective fire protection and a more expensive deluge system.

Consider the following example. The building requiring protection houses a "pull-apart" machine used to disassemble ordnance for either demilitarization or rework. The machine physically pulls apart the explosive device. The "pull-apart" machines are usually well shielded to protect the operation since the greatest chance of an event is during the separation

and possibly the pouring of the propellant. A specification reads: "The ultra-high-speed deluge system in the pull-apart room shall provide water at a density of 0.5 gmp and shall have a response time of 100 milliseconds or less." Also consider that the building is 22 feet x 22 feet with a 10-12 foot ceiling. According to specification, a contractor could provide a ceiling fire protection system consisting of 20 heads.

Further study of the process reveals that the greatest chance of fire will occur when the projectile is pulled apart and when the operator dumps the propellant.

Although the system reacts in 100 milliseconds, the nozzles may be 10 feet away from the hazard, severely increasing the time it takes to get water to the hazard.

Because the specification called for a density of 0.5 gmp an increased amount of money is normally spent on a system with 20 nozzles and 4 detectors instead of a system with 4 nozzles and 2 detectors.

A preferred specification would explain the hazard as well as the operation. The specification should require that a detector be placed close to the point where the projectile is separated. A detector shall also be placed where it can view the propellant dump operation. Two nozzles shall be placed as close as possible to the separation point along with one nozzle to protect the operator when present and another to stop propagation to the powder accumulation area. A flow of 25 gmp per nozzle shall be provided. Nozzles and detectors shall be placed as close as possible to the hazard but not be placed so they can easily be obstructed by machinery or operating personnel."

Although this simplified example only represents a small portion of the specification, it illustrates how a small amount of extra effort can greatly enhance the installed system and save government money.

In the past, it was common practice to copy existing specifications and revise them using the "cut & paste" method. Reworking a specification is an acceptable practice since there is no reason to "reinvent the wheel" each time, but extra care must be taken to assure that the final specification conveys the desired final product. Some actual specifications require 50 milliseconds response in one section and 100 milliseconds response in another.

The contractor installing an ultra-high-speed deluge system must understand the product and process that is being protected. An experienced contractor and a well-written specification are essential for an effective system. This is true of both suppression and detection (see Section III).

2. False Activations

Most false ultra-high-speed deluge system activations result from poor installation, ambient conditions not suitable for the detection system, degradation of equipment or poor system design.

False actuation due to ambient conditions depends upon the detection system being used. Two common types of detectors are in use, ultraviolet and infrared. The ultraviolet is most common. These are discussed in detail in Section III.

Common ambient sources of nonfire radiation (discussed in Section III in detail) that can cause false activation of UV detectors include:

- Long-duration lightning.
- High-voltage corona (transformers or high voltage insulators and lines).
- Static buildup on belts or conveyors (due to the Van DeGraph effect.)
- Cracked lenses in high pressure sodium lights.
- Arc welding up to 1/2 mile
- Drill motors, commutator motors and contacts that emit arc or sparks.
- Sunlight if detector has deteriorated or shifted frequency.
- X-ray/ionizing radiations.

There are many sources of UV radiation. Fortunately, most of them (due to sparking or energy potential), should not be near pyrotechnics or explosives.

The IR detectors that are the state of the art in ammunition plants at this time, are susceptible to ambient light (both sunlight and artificial light) and black body radiation. This type of detector should be installed where there is little or no light. Disconnect switches must be employed if equipment is to be opened to ambient light.

Poor installation is a major cause of false activation.

Age or other degradation of equipment can cause false actuation. Scheduled maintenance and trouble shooting can help prevent this.

False system activation is not always limited to detection. One must be aware of causes stemming from poor interface and control circuitry design.

Large inductive load switching and power source spikes may cause false activation.

False activation often occurs during maintenance and servicing. It is best to have systems in bypass with water off when maintaining systems.

New technology systems such as machine vision will be able to offer better discrimination and fast detection.

3. Reaction Time

Reaction time should be realistic and defined in a manner that will permit meaningful testing of the systems to ensure the performance criteria are met. There has been no common agreement on the definition of deluge system reaction time. This has caused confusion and

prevented the development of a performance-type specification. This precludes the effective evaluation of ultra-high-speed deluge systems.

There is no universally accepted agreement on the definition of deluge system reaction time. The U.S. Army Materiel Command Safety Manual, AMCR 385-100, provides the most complete definition of reaction time. It defines reaction time as: The sensing of a deteaction event by the detectors to the beginning of water flow from the critical nozzle(s) closest to the hazard.

This definition does not consider the time required for the water to travel from the nozzle to the hazard being protected. This is the forgotten factor in the design of ultra-high-speed deluge systems. It is not uncommon to see deluge systems that are specified for 100 ms response time, installed with nuzzles 14 feet above the hazard. Application like this are a waste of effort and provides an ineffective, unsafe system.

Deluge system response time should be redefined as total reaction time. Proposed Definition: Reaction is defined as the total time required from initial fire event detection to water flow maintained at the hazard.

Overall reaction time can be broken down into segments.

By dividing the events of a pyrotechnic fire and deluge system actuation into individual time segments, one can better understand exactly what is being timed and what may be being ignored when the test is performed.

Time Segment 1: The pyrotechnic mix is subject to excessive energy input.

Time Segment 2: Deflagration begins at some point in the mix.

Time Segment 3: The fire develops to a point that puts it in the detector's field of view.

Time Segment 4: The detector begins to react to the fire.

Time Segment 5: The detector "decides" that there is enough light energy radiated to be considered a fire.

Time Segment 6: The detector sends out a fire signal.

Time Segment 7: An interface unit (a unit that provides an output signal compatible with the suppression after receiving a "fire" signal from the detector or detector controller) receives the "fire" signal and activates a squib or solenoid valve, depending on the system type.

Time Segment 8: Mechanical components within the deluge system go into motion.

Time Segment 9: Water leaves the nozzle and travels toward the target (burning

pyrotechnic mix).

Time Segment 10: Water spray impinges on target.

Time Segment 11: Water flow is maintained to achieve the desired effect. (cool down, dispersal and extinguishment.)

With the event divided into 11 short segments (the total time elapsed is usually less than 100 milliseconds (1/10 of a second) for all 11 segments, each segment can be analyzed to determine if the individual time segment's reaction time can be reduced.

The total reaction time must be considered when designing deluge systems. The use of total reaction time provides a means to realistically evaluate the required reaction time of deluge systems. This will also provide a baseline for checking response time during the annual flow test; after a system has been inactive for an extended period of time, or a system has been modified.

Detection time is the time from detector sensing threshold of the fire to the time that the signal is amplified and fires the squib in the valve or opens the solenoid valve. Factors effecting detection time included:

- Distance between detection and target.
- Type of flame and amount of smoke.
- Detector sensitivity.

Water delivery time is the time required from primer firing or solenoid valve opening to the time a fully developed spray of water strikes the hazard. Water delivery time is dependent on several factors:

- Water pressure.

- The distance between the nozzle and hazard.

- Type of nozzle and piping configuration.

- The completeness of the water prime of the piping system from the valve to the nozzles.

Research conducted by various agencies in the DOD establishment and private sector indicates there is a direct relationship between water travel time, water pressure, and nozzle type.

Proper installation is critical to acceptable system reaction speed {of water allowed to flow}. Water contaminated with energetic nature is often a problem at ammunition plants. Excess contamination water may have to be dealt with.

4. Time Testing

Time testing of ultra-high-speed systems is a critical and necessary function of acceptance and maintenance, and these systems should be standardized.

Time testing is an essential aspect of acceptance testing and maintenance. There are many methods of time testing. Probably the best way to determine if the deluge system is adequate is to run an actual fire test with the explosive or high-energy material utilizing a proposed suppression system. Often, this is not feasible. With exception to actual burn test, the second most accurate method of time testing would be using high-speed video cameras.

A high-speed camera is used to record and play back the event and the frames are counted to determine the response time. The propagation of the flame can be observed to the point of detection, the start of flow at the nozzle, and water spray as it progresses to the hazard. Spray patterns can also be observed. This system is sometimes not feasible for "in-field" application. Lighting is sometimes inadequate and the expense of providing the technicians and shipping the equipment is often great.

With advances in technology, price and size of equipment are decreasing rapidly. So far, the most economical and reliable system for "in-field" time testing is a digital timer. Reaction time is defined here as "beginning at instant of detection and stopping at flow from nozzle." The timer is started by a signal from detection control and is stopped by a flow switch connected at the nozzle. This seems to be acceptable to most authorities for testing deluge systems "in-field" and for periodic maintenance testing.

A trend is developing in specifications to time the system from initiation of a saturating light source to receipt of "fire" signal to flow at nozzle. This method provides for the testing of the integrity and speed of the detection portion of the system. The preferred instrument set-up for this method would provide two timer readouts. The first would represent the detection time (saturation of detector to out-of-fire signal) and the second readout would represent deluge system response time (receipt of fire signal to flow at nozzle). When using this type of time test, the specification writer must consider the added detection time.

The first time test method uses high-speed video technology. It allows viewing and testing of Segment 3 through Segment 11.

The second time test method mentioned measures the point of detection to flow at nozzle. This method allows timing of Segments 6 through 9.

The third method, detector saturation to flow at nozzles, measures the total time of Segments 4 through 9.

It is possible to measure water spray impingement on the target (water travel time) or segment 10 using the second or third method.

The time tests are critically different. They all have advantages and disadvantages. The individual involved in providing, testing and specifying deluge systems must be aware of the methods and their shortcomings.

Proper installation is also imperative to achieve a useful and functional fire protection system. One of the most critical areas is the electrical installation of the system, especially the detector's wiring and installation. False actuation or no actuation can result from a poorly installed detection system.

F. IMPROVING EXISTING SYSTEMS

Improving existing systems must be done on an individual, one-on-one basis. Each system must be evaluated and studied to determine if it meets existing criteria. The existing systems vary greatly.

Some deluge systems could not react in less than 2 seconds (2000 milliseconds). When these systems were installed they did meet specifications and were state of the art. Extensive renovation would be required on such systems.

Other installed systems may need only minor adjustment and Other installed systems may need only minor modifications such as:

ž Relocate detectors.
ž Perform time testing.
ž Change design criteria in cases where the hazard has changed.
ž Eliminate or enhance overhead deluge with dedicated "pin-point" deluge.
ž Study available underground supply, as smaller well designed systems may do a better job and require less water than a large poorly designed system.

G. SUMMARY OF TYPES OF ULTRA-HIGH-SPEED SYSTEMS

Advancements in electronic fire detection in the past twenty years has made ultra-high-speed deluge systems for explosive facilities feasible and reliable. Discussed as follows are ultra-high-speed fire suppression systems presently used in explosive facilities, along with a newly proposed propellant driven system.

1. Explosive Squib Actuated Valve

The Primac is a squib-actuated deluge valve. The system uses one large valve connected to a preprimed piping system utilizing nozzles with end caps or rupture discs. In Primac Systems using rupture discs at the nozzle, the rupture discs are burst by water pressure, not an explosive charge. The body of the Primac valve is that of a standard "globe" valve. The water seal is achieved by a piston entering the throat of the valve body. An "O" ring inserted in the same manner as a piston ring makes the piston watertight. The stem attached to the piston extends through the top of the valve. A swinging latch connecting this stem holds the

valve in a closed position. The yoke supporting the latch is designed to accommodate a primer so positioned that when the primer detonates, the latch is forced off the stem and the water pressure under the piston opens the valve. (Figure 1)

2. Explosive Rupture Disk

The explosive rupture disc system incorporates the same principle as Halon-type explosive disc systems, except that water is used as the extinguishing agent. This type of system is very effective in flooding large vessels quickly. In ultra-high-speed applications, where large coverage or many nozzles are required, there is a squib and rupture disc at each nozzle.

3. Pilot-Operated System

The solenoid-operated system does not use explosive squibs. Its principal of operation varies greatly from the previous two. When pilot pressure is relieved, all valves connected to the one pilot lines open instantaneously and simultaneously. When the pilot pressure is restored, the nozzles close. A valve consists of a two piece body threaded together and sealed with an "O" ring.

The upper body has a connection for installation and standard pipe fittings and a ¼ inch NPT female connection from the pilot line. The cylinder and the poppet, that make up the differential valve, receive pilot pressure from the pilot-line system. (Figure 2)

4. Propellant-Actuated System

A new area of technology that offers considerable promise to the fire suppression and extinguishing industry is the solid-propellant technology being applied for inflation of automobile air bags. These bags are inflated very rapidly (typically 30 milliseconds for a driver air bag and about 80 milliseconds for a passenger bag) by solid-propellant gas generators that produce gaseous nitrogen as the output product. The nitrogen is formed by the rapid combustion of pellets within the inflator that are comprised of sodium azide fuel with a suitable oxidizer such as iron oxide.

A unique means for employing these nitrogen-producing gas generators in fire extinguishment applications would be to use the gas generators as a means for rapidly expelling and atomizing water stored in a pressure vessel located near a hazard. This method is more suitable for pyrotechnic fires. When the gas generator was electrically initiated by the fire/explosion sensor, the water reservoir would be rapidly pressurized to a pressure of around 2500 psig, which would rupture the diaphragm retaining the water in the reservoir and allow water to be expelled through the outlet port. The high operational pressures available would allow the outlet port to be designed as an efficient atomizing nozzle to disperse the water into fine droplets, which would increase the effectiveness of the system. Although this approach results in a "one-shot" device, several of the gas generator actuated vessels could be placed at each hazard to provide multishot capability. A potential advantage of these propellant pressurized water reservoirs would be the minimal amount of water that was expelled in each

event. (Figure 3)

With the various systems available for the suppression of high energy chemical fires, there is a configuration suitable for almost any explosives, pyrotechnic or munitions facility.

H. SUMMARY

Standardization of specifications and testing methods require further study and improvement.

Future systems must be designed and specified with the individual hazard in mind. There has been much improvement in this area in recent years, i.e., detector and nozzle placement. A hazard analysis is recommended for any proposed system. The analysis should include a study of product and process.

At this time, there is not extensive available information on the various pyrotechnic, explosive and propellants used in the munitions industries. The type of information being: spectral wavelength emissions of the burning product, the effect of water in extinguishing fire in the various products, and the speed required to extinguish a fire involving the product and processes.

Due to the lack of specific information on the burn characteristics, a design goal is to get the most water to the hazard as quickly as possible. With better statistics and information relating to the individual burn characteristics, money may be saved by eliminating some systems or at least fine tuning (or optimizing) them to the hazard. With more data on frequency emissions, detector manufacturers could also design their detectors to be more specific to better match detection bands to those of individual pyrotechnic materials' emissions.

SECTION III

FIRE/EXPLOSION DETECTION

A.   REQUIREMENTS

The two most important requirements of the fire detector are fast detection of a pyrotechnic fire/explosive event and reliable, false alarm-proof operation. It is of utmost importance to identify the event in time to apply the suppressant to the developing fire event before a catastrophic situation occurs. It is also important that the detector does not false alarm to a nonfire event, thus causing the accidental release of the suppressant, which could result in an extended downtime of the fire protection system and production line, financial loss, and adverse environmental impact. This latter problem is becoming more severe with increasing knowledge of the effects of certain types of fire extinguishing agents on the atmosphere and water aquifers.

In addition to "speed of response" and "immunity to false alarms," other operational features

should be considered in selecting a detector, or detection system, for any specific application. These include:

- Ability to meet environmental and mil-specifications
- Logistics: ease of installation and maintenance
- High mission success reliability
- Reasonable MTBF
- Self-test

B. DETECTOR BACKGROUND

The types of detectors used over the past 10 years in monitoring ammunition maintenance, storage, renovation, rework, processing, and manufacturing activities are basically the same detectors used for hydrocarbon fire detection such as in commercial and military aircraft facility applications. These conventional detectors are typically single band IR, single band UV, and, recently, a combination of both UV and IR. Their operational spectral bands are primarily those associated with hydrocarbon- based fires. The intensity of these radiations is used as a criterion to determine the presence of a fire of some minimum size at some distance. Due to the 1/r2 law it is impossible for such a detector to determine actual size, location, or even direction unless the detector functions in the video/image processing mode such as the machine vision detector being developed by Donmar Ltd. for the Air Force.

Hydrocarbon fires have broad wavelength band emissions across the ultraviolet, visible, and infrared portions of the electromagnetic spectrum. However, there are certain discrete emission characteristics such as the CO2 emission "spike" near 4.4µm. Also, because the atmosphere absorbs most solar radiation in the 185 nm - 240 nm ultraviolet band, the relatively low level of ultraviolet emitted by hydrocarbon fires in this band (as compared to the IR emission at 4.4µm) can be distinguished above the background solar radiation. For these reasons, most commercial grade fire detectors used for hydrocarbon fire detection operate in the 185nm - 260nm ultraviolet band and in the 4.2µm - 4.7µm infrared band. These same detectors, when applied to the pyrotechnic fire application also use the same spectral bands, but not by design.

The spectral emission characteristics of hydrocarbon and pyrotechnic fuel fires are different, but there appears to be considerable overlap across the UV band and in the IR band near 4.4µm. There is a distinct emission near 4.35µm from propellant ignition. In general, however, there is insufficient pyrotechnic spectral irradiance information to design a detector to the specificity needed to optimize detection and discriminate of a pyrotechnic fire from other sources of the same radiations.

Commercial type detectors have been augmented, to some degree, in their "sensitivity" to detect pyrotechnic-type fires much faster than hydrocarbon fuel fires where the required time-of-response may be much longer (e.g., 5 seconds as compared to tens of milliseconds).

In the process of increasing the sensitivity, and therefore reducing the threshold of either

count rate or spectral irradiance, an increase also results in the detector's sensitivity to respond to nonfire sources which radiate in the same spectral bands at a spectral irradiance level at the detector which is equal to or greater than the threshold for pyrotechnic event detection. Therefore, at some sensitivity level, the detector becomes sensitive to nonfire sources within its field-of-view and may lose its immunity to false alarms, thus becoming a liability rather than an asset to fire/ explosion protection. At this stage false alarms occur. This depends, however, on the nature and properties of the nonfire radiative sources in the detector's FOV. False alarms have evidently occurred in various pyrotechnic and ammunition facilities, but documentation is either scarce or is inconclusive as to the cause of the false alarm. Welding and lightning have been cited as causes on several occasions.

Again, speed and reliability of detector response are the most important parameters in this fire detection application. There are basically three types of detectors that should be considered for this application, namely, UV, IR, and machine vision (either in the visible or IR).

C. UV DETECTORS

Historically, the UV detector has been used for pyrotechnic and propellant fire detection for the past 20 years. Its operational characteristics have been documented many times in reports pertaining to this fire protection problem. Because of its "Geiger-Mueller" detection morphology, it is a very sensitive detector that can respond to either a photon of energy equal to or greater than some "work function" energy associated with the cathode material, or charged particle that can interact directly with the gas molecules.

When a photon strikes the cathode, usually tungsten, an electron is emitted. Tungsten has a work function that will allow, as a minimum, a photon of wavelength 0.245μm (245nm) to cause an electron to be emitted from the cathode. The emitted electron is drawn to the positively charged anode and, enroute, strikes gas molecules which are then ionized, thus resulting in a current between cathode and anode. An avalanche/discharge occurs which can be interrupted by switching the power on and off or by reversing the charge on the cathode and anode.

The glass envelope, usually quartz, is opaque to wavelengths shorter than about 185nm. Therefore, the spectral UV sensitivity of the UV detector is usually between 185 nm and 245 nm, although the cutoffs extend to longer and shorter wavelengths. This type of detector is a relative intensity detector, that does not know the nature, direction, distance, or spectral irradiance of the source. It cannot discriminate spectral energy flux (spectral irradiance) because it will respond to all energies equal to or greater than the specific work function of the cathode and to any source that causes ionization of the fill gas(es) to occur.

One problem is that this type of UV detector may be too sensitive to extraneous UV, charged particles such as cosmic rays, and other ionizing radiations. To circumvent this sensitivity problem, the electronics can be programmed to activate an alarm/suppressant dump only when the count rate reaches some minimum level over some gated time sequence, which is normally above the estimated background count rate or other possible count rates caused by

nonfire sources.

The UV detector has been tested in many pyrotechnic and propellant fire/explosion tests and has demonstrated a broad detection-time-range of about 20 ms to about 800 ms, depending upon the substance being burned and its properties, detector look angle, distance, number of detectors used in the detection scheme, and other parameters. "Detection time" is defined herein by the number of counts accumulated over some predetermined time period. The fewer the number of counts required to respond with a "fire decision," the more susceptible one detector is to false alarming to extraneous nonfire sources.

UV detectors are greatly affected by smoke in the path between the fire event and detector. In tests with burning smoke mixes, UV detectors were unable to "see" a flame signature for relatively long periods after ignition, sometimes seconds. In extreme cases, the flame was so obscured from the UV detector by the smoke from the mix burned, that more than two minutes elapsed before the detector responded. In other cases, the smoke was relatively dense around the detector's lens face, thus fooling the detector's BIT into "thinking" the lens was "dirty," thereby setting off a fault alarm.

Despite the problems with UV detectors, they are very effective in certain applications. Instead of designing the detector to meet the specific application, efforts have been devoted to modifying standard commercial hydrocarbon flame detectors to perform as pyrotechnic and propellant fire detectors or smoke/flame detectors. To some degree, these efforts have been successful, but the time of response and false-alarm immunity requirements remain to be satisfied. To optimize the detection morphology, (1) the detector's operating spectral bands should be the same as the spectral emission bands of the munitions/propellant substance fire; (2) the required count rate to assuredly identify a fire event should be minimized; and (3) the detector should be immune to nonfire sources.

D. IR DETECTORS

In addition to UV and visible radiation, fires also produce substantial amounts of infrared radiation in the near and mid-IR regions. Most of the emission characteristics pertain to "blackbody" emission which covers a broad range of the IR spectrum. Some "species-distinct" emission "spikes" occur, especially near 4.4µm. This emission characteristic is due to carbon dioxide. It is also an important fire feature to monitor because the atmosphere absorbs solar radiation in this wavelength region, thus minimizing the background. Another "window" region, sometimes used for IR detection, is near 1.2µm.

IR detectors can be very sensitive to almost any "hot" body because this body radiates across a broad spectrum of the near and mid-IR spectrum, taking the appearance of a bell-shaped curve whose peak intensity corresponds to a wavelength that varies with temperature. The IR spectral radiance of a pyrotechnic/propellant material fire is much greater than that in the UV, in fact, orders of magnitude greater. Also, IR detectors can "measure" the relative spectral radiance from an event, thus being able to associate "intensity" with relative size and/or distance of the fire source. UV detectors cannot function in this manner due to the work

function of the material of the cathode and the cutoff energy of the tube's glass.

IR detectors, used in hydrocarbon fire detection, have not demonstrated, to a great degree, reliability to discriminate fire from hot bodies and nonfire sources. Two basic types of sensors are used in these detectors: thermopile and pyroelectric. The thermopile is similar to a thermocouple. Because many "thermocouples" can be connected in series on the same chip, such a detector can be very sensitive. They are, however, very sensitive to ambient temperature changes.

Pyroelectric detectors use photodiodes and operate on the basis of time rate of temperature change. The output depends upon the time rate of change in the detector's temperature rather than on the detector temperature itself. It is constructed of a pyroelectric crystal such as lithium tantalate or ceramic barium titanate. When these crystals are exposed to thermal gradients, they produce electrical current.

One characteristic of fire is "flicker." Flicker is the result of dynamic behavior of the flame and produces an intensity variation in the IR and visible in the range of 1-20 Hz. However, in tests conducted by Donmar, flicker can be seen to occur on even the highest frame rate video CCD cameras, certainly over 1000 frames per second (2 interlaced fields per frame). Because of this fire flicker property, almost all IR fire detectors require a flicker to exist in the IR signal processing. However, a flicker can respond to any motion such as walking or a moving vehicle in between the detector and the nonfire IR source to cause a false alarm. Another feature of fast ignition/growth pyrotechnic events is that the event is extremely intense in the far UV, visible and near infrared and does not contain flicker until the "fire" part of the event begins, some 50 milliseconds or so after substance ignition. Flicker, then, is not necessarily useful as a detection criterion, although it may be helpful as a false alarm discriminator if the time of response of detection is greater than 2-3 seconds.

Other infrared detectors are currently being used in Army Tanks and fighting vehicles to detect armor piercing ammunition and to discriminate them from "heat rounds" and other non-ammunition fire sources of infrared. These detectors operate in the 2-3 millisecond time period when responding to a small 5-inch x 5-inch fire at distances as close as 2 feet- 4 feet. However, the response times increase as distance increases. In a commercial fire detection application, the response times may be as long as 3-5 seconds for a 1 ft^2 pan fire at 40 feet distance.

E. MACHINE VISION FIRE DETECTOR SYSTEM (MVFDS)

Machine vision technology provides the means by which information can be automatically extracted by computer processing of video imagery whereby certain preprogrammed patterns, spectral properties, or changes are searched for and, if found, provide the basis of some form of deduction and/or decision. The technology enables reliable and rapid discrimination of objects and phenomena from a very large variety of very similar objects and phenomena having almost identical spectral features in the visible region, although the infrared region can also be used.

Images/scenes, obtained by either color or black and white CCD (Charge Coupled Device) cameras, can be grabbed, stored, and processed with algorithms at very high frame rates. A machine vision system can be adaptive and "learn" to recognize images, spectral features, changes, and physical features, and to make decisions based upon these analyses. In other words, machine vision emulates the human process of "seeing" an object, action, or phenomenon with the eye, and determining with the brain what it is and what action to take. A human uses stored knowledge and experience to make these decisions. In a machine vision system, vision with the eye is replaced with a lens and Charged Coupled Device chip. Knowledge is replaced with stored information. Experience is replaced by algorithm processing and comparison. And decisions are based upon satisfying required yes and/or no answers, usually several in parallel. The differences between human and machine vision are: machine vision is much faster, more accurate, and more reliable.

The approach taken to fire detection is derived from physical models for the formation of images of fires and other stimuli. From these physical models various properties derivable from color or black and white image measurements that can be used to distinguish reliably fires from other events are defined and quantified. These properties can be computed at high-speed and together with a decision procedure form the basis of a fire detection system. This system is capable of rapidly identifying fire events (in the millisecond time range) and determining in real time the corresponding size, growth rate, distance and location of the event in the scene. The effectiveness of these properties for fire identification has been demonstrated to the Air Force both analytically as well as experimentally on real fires, sequences of color images of fires, and possible false alarm sources.

For current fire detection applications, the frame grabber is designed to acquire digital color images and store them in computer memory at the standard video rate of 30 frames per second. Only 3-4 frames are necessary to discriminate fire. Once the frames are in computer memory, the images may be analyzed by a digital processor. In applications such as pyrotechnic fires, using existing technology, speeds of only a few milliseconds can be attained. This fast speed detector is also being developed by the Air Force for aircraft munitions fire/explosion detection.

The color images acquired by the frame grabber are represented hierarchically as a set of two-dimensional blocks that are processed individually by the fire detection algorithms. Each block corresponds to a specific area in the monitored scene and the size of each block is proportional to the corresponding area in the scene. As frames are acquired, the system control structure incrementally updates the current status and characteristics of each block. Once a contiguous array of blocks is identified as corresponding to a fire event the system will activate an alarm, if required. When sufficient number of contiguous blocks are equivalent to a specified fire size, the system will take the appropriate programmed action, such as an automatic release of suppressant at the location of the fire. The detector also produces a video output, thus allowing manual override of any automated suppressant release action, if desired.

This process may seem long, but it actually occurs in only tenths of a second for hydrocarbon

fire detection applications using very commercial, conventional, off-the-shelf hardware/software. For the application to detection of pyrotechnic/propellant fires and explosive events the algorithms are simplified according to the physical characteristics of the detonation/fire event. These data are available in fast speed color video and can be used to refine existing and develop new algorithms.

The Machine Vision Fire Detector System (MVFDS) is being developed by Donmar Limited for Air Force ground-based applications such as aircraft hangars and shelters, and will soon enter development for Air Force aircraft airborne applications, such as fire/explosion detection in aircraft drybays and engine bay compartments.

Hardware is presently available that can perform at speeds fast enough to capture three or more frames of an explosion in the 20 ms period.

The MVFDS, in a fast-speed configuration, appears to be a potential high reliability detector of pyrotechnic and propellant events at their early ignition stage. The system provides so many other features in safety and fire protection that it should be closely examined for further development and test. These features include: intrusion detection; simultaneous video surveillance and fire detection; manual override of fire suppression system for slow burning, low threat fires; determination of location and distance of fire events, thereby allowing selective discharge of local fire suppressors and thus reducing cost and potential environmental effects. For more information on the characteristics of machine vision fire detection, refer to "Machine Vision Fire Detection System Development", Goedeke, A. Donald, Drda, B., and Healey, Glenn, Final Report, Contract F08635-91-C-0217, WL-TR-93-3514, Sponsor WL/FIVCF, Tyndall AFB, FL, March, 1993.

F. FALSE ALARM SUSCEPTIBILITY

As discussed above, the basic threshold of a fire detector is the spectral irradiance value set for the source to be detected, at its specified maximum distance from the detector. This spectral irradiance is usually determined for a spectral band which corresponds, or overlaps, with the wavelength regions where the detector's sensors operate. For instance, most UV detectors operate in the spectral band of about 185 nm - 260 nm. If the detector is required to identify some type of fire, for example JP-4 fuel, of a certain minimum size at some maximum distance in some maximum time period, the detector is responding to the spectral irradiance from the source at the distance of the detector. If the fire's spectral irradiance is equal to the threshold value at the detector's distance, say "x," then any spectral irradiance in the same spectral band that is equal to or greater than "x" will cause the detector to alarm. Likewise, any spectral irradiance from any other nonfire source will also cause the detector to respond. This "false alarming" potential is a problem in some applications and, especially, in locations where many nonfire UV and IR sources can exist, either singly or in multiples.

Some detectors, such as UV/IR dual band detectors, are less susceptible to false alarming because both their UV and IR spectral irradiance threshold bands must be satisfied before an alarm is activated or suppressant is released. In addition, most manufacturers have also added

another feature, described earlier, that requires at least the IR radiation to show a modulation of some "flicker" in the 1-10 Hz range. However, as found in detector false alarm studies, this flicker requirement can also be satisfied simply by moving objects between the detector and the radiation source(s). Therefore, false alarms still occur, but are less frequent with this added flicker requirement.

Knowing the spectral irradiance then, of the type of fire/explosion source to be detected at some minimum specified distance in some maximum specified time, it would be a simple task to identify, and possibly eliminate, some, if not all, possible false alarm sources. For UV,IR and UV/IR detectors, this is possible if the spectral irradiance of the possible false alarm source is known. However, the only way to discriminate against such false alarm sources using UV, IR, or UV/IR detectors is to either locate the false alarm source further away from the detector, thus reducing their spectral irradiance to a value less than the threshold value of the fire to be detected, or replacing it with a more benign type, or simply eliminating it. In this manner, a facility can be designed to pose minimum false alarm problems to the fire detection system, especially if the system is a very fast reacting system that is very susceptible to only small values of spectral irradiances. A machine vision detector, however, can discriminate these false alarm sources even though they are in the detector's field of vision.

The number of possible false alarm sources covering the electromagnetic spectrum seems to indicate that sources in the visible region would pose a greater false alarm problem than sources in either the UV or IR. This may be true provided the method of detection is based upon intensity only. Machine vision, on the other hand, although it operates in the visible part of the electromagnetic spectrum (it can also use IR), relies on intensity and many physical, temporal, and spatial features unique to the fire event. While UV and IR emissions are commonplace and can come from any direction or even one object (e.g. incandescent 150W lamp), the visible radiation must be in the form of the image of the fire object itself and behave just as the fire object behaves. Pattern recognition, artificial intelligence, and computer image processing then play the predominant roles in machine vision fire detection, making it less susceptible to false alarms.

G. FALSE ALARM SOURCES

Many types of nonfire sources of UV, visible, and IR radiation could make optical fire detectors false alarm and cause the accidental release of suppressant. A list of such sources is listed in Table 1. Several may not have application to Army munition fire detection, but these are included as reference.

Among the many types and varieties of potential false alarm sources, many were subjected to laboratory measurements and tests in a recent detailed study. (See Final Report: "Characteristics of Optical Fire Detector False Alarm Sources and Qualification Test Procedures to Prove Immunity," Goedeke, A.D. Contract No. F08635-91-C-0129, CEL-TR-92-62, Sponsor HQ AFCESA/RACF, October, 1992.) Some of the particular radiation sources studied are listed in Table 2. These sources, of course, include items not normally found in or near an ammunition/ pyrotechnic facility, but are included herein as

examples. The fire to be detected was assumed to be a JP-4 fuel fire of size 2 feet x 2 feet at a distance of 100 feet (it is understood that the spectral emissions from JP-4 are different than those from a pyrotechnic material fire, especially at the onset of the event; they are used here for reference).

1. Measurement Data and Computed Irradiances

Extensive measurements were made of each source in the bands 254 nm, 300 nm, 365 nm, 405 nm, and 450 nm, respectively. Because atmospheric transmittance can be changing considerably in the UV and IR bands of interest, both the inverse square law and the Lambert-Beer-Bouguer law were applied simultaneously to the measured values to derive the corrected values. Figures 4, 5, and 6 show only a few of the many spectral irradiance curves measured in the three spectral bands of interest. As seen in the curves, the most drastic falloff occurs over the range close to each source. It is important then that appropriate correction be made for atmospheric transmission over the distance of the measured and computed extensive values.

The data in Figures 4, 5, and 6 are plotted for two UV bands and one IR band. The UV fire detectors respond to the burning JP-4 or pyrotechnic material irradiances in the 200 nm and 254 nm bands. The IR band at 4.4 micrometers likewise is a well known feature of burning hydrocarbon fuels and pyrotechnics, being specifically considered because of high atmospheric transmittance in this region.

One of the most common performance criteria set for most fire detectors is that it must be able to detect a 2-foot x 2-foot square pan fire of JP-4 fuel or gasoline at a distance of 100 feet in 5 seconds or less (after the fire has reached full size). The horizontal straight line across each figure corresponds to the irradiance value from such a "design performance fire" for the spectral band being considered. Where two horizontal lines occur, which defines a "band", this helps to point out that there is no single <u>unique</u> value of irradiance for burning JP-4 (or pyrotechnic material) at 100 feet distance or any distance. Each pan fire can vary in this respect, depending on a variety of conditions, such as wind and humidity. Hence, a p3P/ spread of values is to be expected. The horizontal lines used here are based upon the actual JP-4-burn measurements.

The standard JP-4 fire detection criterion is used here because the detectors used for ammunition/pyrotechnic fire detection are normally based upon these measurement specifications/ standards, although altered to some degree to decrease the time of response to tens of milliseconds. Note also that the spectralirradiances of emission properties in both UV and IR from pyrotechnic material combustion/explosion are not known. Such information is almost a necessity in designing specificity into a detector's mode of operation, wavelength bands, and response time.

With the horizontal straight lines serving as the detection criteria to be satisfied, all curves that extend above these lines show irradiance values that could trigger false alarms (again assuming a 2 foot x 2 foot JP-4 fire at 100 feet). This is true over the range of distances

where each curve goes above the detection criterion. If the detection criteria differ as to the fire type, size, and distance, a separate horizontal irradiance line would have to be determined for each. This needs to be accomplished for Army munitions applications to establish a scientific basis for maximizing a detector's performance and minimizing its susceptibility to false alarms.

For the distances where the curves are below the detection criterion, however, each radiation source individually would not have sufficient irradiance to trigger a false alarm. By superimposing additively the irradiances of two or more sources at such distances, it is possible to obtain a combined irradiance that may trigger a false alarm. Such combinations could be estimated from the curves.

Study across all curves of the three bands shows that the steepest rolloff is within about the first 20 feet. Thereafter the rolloff of irradiance with distance is more and more gradual.

Hence, it was shown that:

1. Individual radiation sources can trigger a false alarm within the distance over which their irradiance exceeds the detection threshold criterion.

2. Individual sources cannot trigger a false alarm for distances where their irradiance is below the detection criterion.

3. A combination of radiation sources of the kind in (2) above can be combined to trigger a false alarm.

Eight commercially available detectors, including UV, IR, and UV/IR types, were used in tests to determine the effects of the potential false alarm sources. The detectors tested were set by the manufacturers to the following fire threshold: 2-foot x 2-foot JP-4 pan fire at 100 feet within 5 seconds of the fire attaining full size. This is a standard Army Corps of Engineers and Air Force specification (Air Force Requirement AFR 88-15, <u>Criteria And Standards For Air Force Construction, January 1986)</u> for fire detectors in hangars and shelters. It was found that the "fire detection threshold" of each detector differed somewhat against the same sources (butane flame and propane flame) at the same distance.

Comparing the chopped data with unchopped data, it was evident that the straight flux from either AC or DC operated light sources is not sufficient, in general, to trigger all detectors. However, where the source flux is chopped, all the detectors are triggered to false alarm. Response of the detectors, at least those used in these tests, is therefore controlled by the particular frequency response "window" designed into the detector and, of course, the value of the spectral irradiance of the nonfire source in the wavelength band of interest. As stated earlier, however, use of flicker as a detection criterion, may not be advantageous in pyrotechnic material fire detection because it would slow down the overall detection time.

It was also found that there is a pronounced effect on detectors to alarm when the lamp's glass

cover plate is removed or cracked/broken. The implication is that radiation in the 200 nm UV band is not reduced greatly by the protective window, but rather by the outer bulb of the lamp itself, if it has one. If the outer bulb, however, were to crack or rupture, the UV radiation emanating from the lamp would be much greater than normal. Such circumstances, where a small hole or crack occurs in the outer bulb, could enhance the probability of a false alarm event. We were unable in this brief study to find documentation whether such events have been reported in Army munitions plants.

Analysis showed that the potential of false alarms is much greater when two or more UV and/or IR radiation emitters are present in the FOV of a detector and that the sources have enough radiance in the detector's operating spectral bands to equal or exceed the fire detection threshold irradiances at the distance of the detector. A standard 300 watt Quartz Tungsten Halogen (QTH) work lamp, with its glass cover plate on, has an irradiance in the 185 nm to 250 nm band at about 30 feet distance which is equivalent to a 2 foot x 2 foot JP-4 pan fire at 100 feet in the same spectral band. This means that this lamp alone, located at 1 - 30 feet from the detector, may satisfy the UV irradiance threshold value required by a fire detector to alarm (in this case to a 2' x 2' JP-4 fire at 100' or less), provided other p3P/ factors (e.g. flicker), if any, are also satisfied.

It would be prudent to determine the spectral irradiances of the many types of possible false alarm sources that may exist in the vicinity of, or in the approximate field-of-view of, the fire detection system. It would also be prudent to require qualification performance testing on detectors being considered for acquisition <u>before</u> the detectors are acquired and installed. The detectors should be immune to any scenario that includes the presence of one or more of the possible sources of UV, IR, and visible radiation.

The study was limited in time and in scope, but there were significant observations made regarding pyrotechnic/ammunition materials fire protection systems. Several major observations were made which led to the conclusions stated earlier, which form the basis of the following recommendations.

A. GENERAL OBSERVATIONS

The current fire detection and suppression technologies being applied in Army ammunition/propellant-related facilities should be thoroughly reviewed with respect to the threat, required reliability, desired performance criteria, and overall mission success goals. The fire/explosion threat needs definition in terms of the system performance requirements to quell the threat before any loss of resources or life occurs. The basic parameters are known through the use of fast video data and during past experiments and field tests. It can safely be stated that test results indicate a need for faster and more reliable fire detection <u>and</u> suppression approaches. Current systems are, in general, satisfactory for some pyrotechnic fire events, but lack the necessary speed and effectiveness for other events. Reliability is also an apparent problem in that false alarms/false dumps continue to occur, although they have not been thoroughly documented or their causes determined in detail.

In other words, there is a lack of scientific information pertaining to the nature and properties of the fire/explosion events, as well as to the reasons for false alarms. Use of deluge water suppression and single band UV detectors should be more thoroughly reviewed in terms of their operational characteristics, performance, and reliability. New technology approaches to these problems should also be reviewed and analyzed with respect to the application requirements, and compared to existing, but older, technology. Selected new technology systems, specifically designed to maximize effectiveness, should then be tested against real fire/explosion events.

It was also apparent from the study that formal guidance is lacking for Hazard Class 1.3 protective features compared to the information for Class 1.1 protective features (TM 5-1300, "Structures to Resist the Effects of accidental Explosions [Tri-Service Manual]).

B. RECOMMENDATIONS

From such a study and tests conclusion can be drawn regarding the best potential approaches to solve the problems. This would include fire detection and suppression system options that should be tested against to select the optimum approach. Once selected, the approach should be developed in hardware and tested in operational environments. The following are the specific recommendations.

1. A review should be made of past reports of fire events and false alarm events. Efforts should be made to determine their nature, cause, and impact, both financially and operationally. It was found in this study that such information is scarce although it is generally known in the industry that such events have occurred.

2. Determine the problems associated with currently installed detectors. This will involve travel to several sites and discussions with facility personnel. Records, if any, would be obtained regarding past history of fire events and detector response. False alarm reports, if they exist, would also be analyzed. Field tests would be performed on several selected existing detection/suppression systems to measure response times.

3. It is necessary to determine the UV, visible, and IR spectral irradiances (in several bands) of various pyrotechnic material fires/explosions. This would be accomplished by obtaining any existing reports or data and experimentally measuring spectral emissions during burns of the pyrotechnic/ordnance materials. No spectral data appear to exist in the available literature that definitive the spectral emission properties. Knowing the wavelength regions where maximum emissions occur during ordnance material burns will dictate the optimum spectral bands where the detector should operate. The effort would also determine what sources of UV/IR/visible may cause false alarms.

This experimental effort would involve field burn tests of several selected materials. Spectrometer data would be obtained in selected bands and irradiances determined. The tests require some safety precautions, as the optical instrumentation will have to be located close enough to the ignition source to be able to maintain the image in the total field of view. The

equipment will have to be rented or purchased. Two spectrometers would be required: (1) UV through visible (185 nm - 900 nm); and (2) near IR (1-5μm). Also, a multichannel data recorder interfaced to a CCD would be necessary because of the short time duration of the event.

During this task, it would also be necessary to measure the emission characteristics from objects/phenomena that are not ordnance fire related. This would include several possible false alarm sources.

4. The data obtained should be used to determine the detection and false alarm immunity characteristics of present day detectors used for munitions fire detection. This would require the acquisition of detectors presently in use for such applications, as well as detectors that should be evaluated for such applications, such as the machine vision detector.

5. Tests should then be conducted in the lab on the response characteristics of each detector to nonfire source. Lab fixtures and test configurations would be built. False alarm sources would be mounted in appropriate lab fixtures.

Detector responses to pyrotechnic/ordnance fire events should be conducted at a "safe" facility, such as at Crane, IN. If possible, simulations could be used of the emissions from the events. For machine vision, video fire data should also be used.

6. A concept design should then be developed for an optimized detection system.

7. The next recommendation would be to design, develop, configure and test an optimized detection system.

8. Acquire, install and test a complete advance technology fire detection and suppression system. During the tests, test the performance of the machine vision detector vs. other detection morphologies. This includes modifications to the machine vision detection mode to be applicable to "fast response" as well as semi-fast response to certain events.

9. Prepare a final report that is a specification for both an optimized system and a future generation/advanced system. Include in final report a design handbook to provide general design information on optimization.

10. Proceed with the optimization of current systems, including deluge subsystems. The latter subsystems require special engineering and technical knowledge and should only be further developed/augmented by recognized, experienced professionals with demonstrated expertise in this area. The AMCCOM Safety Office should be an integral part of this effort, as they are recognized as the center of expertise on deluge systems.

SECTION V

FOLLOW ON PROJECT

The Project Manager for Ammunition Logistics is funding a follow on project for Advanced Fire Protection Deluge System for U.S. Army Ammunition Plants and Depots.

The objectives of the project is to:

The research effort will expand on previous work to include the development of false alarm stimuli data which causes false alarms in UV and IR detectors; validating the detectability of pyrotechnic and propellant material flash fires; designing, operationally testing, and validating a prototype system; and foremost, introducing new and superior technologies which enhance the capability of current systems to react faster to burning energetic materials. The feasibility of applying the new technologies developed by this project to tanks, armored personnel carriers, armored resupply vehicles, other armored vehicles will be examined.

The principle technical risk associated with this effort is providing reliability in the fire detection and suppression system without sacrificing speed. The development of false alarm stimuli will be a major step toward optimizing the current systems and preventing false activations in UV detectors.

An additional objective of this project is the optimization of existing systems through upgrades, modifications, technical enhancements, and operational procedures.

The deliverables of the project include:

> Design drawings, specifications, and recommendations for optimizing existing ultra-high-speed detection and suppression systems.
>
> As built drawings depicting system installation.
>
> A design handbook to provide general design criteria for ultra-high-speed deluge systems located in ordnance manufacturing, maintenance, renovation and storage locations.
>
> A technical report will document all work performed.

SECTION VI

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TABLE 1

Technical Categories of Possible False Alarm Sources

1. Lights

    1.1 High Intensity Discharge (HID) Lamps

        1.1.1 High Pressure Sodium
        1.1.2 Mercury Vapor
        1.1.3 Metal Halide
        1.1.4 Low Pressure Sodium
        1.1.5 Xenon

    1.2 Fluorescent Lamps (96 inch length)

        1.2.1 Cool White
        1.2.2 Deluxe Cool White
        1.2.3 Warm White
        1.2.4 Deluxe Warm White
        1.2.5 White
        1.2.6 Daylight
        1.2.7 Black Light

    1.3 Incandescent Lamps

        1.3.1 Quartz Tungsten Halogen

        1.3.2 Sealed Beam - Automotive:

            1.3.2.1 Headlamp
            1.3.2.2 Spotlamp
            1.3.2.3 Signal
            1.3.2.4 Light Bar
            1.3.2.5 Rotating Lights

        1.3.3 Flashlight
        1.3.4 Flashlight with Red Lens
        1.3.5 Rough Service
        1.3.6 Movie Projector
        1.3.7 Blue Green Dome Light
        1.3.8 Red Light
        1.3.9 Vehicle Infrared Light

2. Reflected Light

Solar and/or artificial light reflecting from painted surfaces, metallic surfaces, plastics, standing water, ice and glass.

3. Natural Phenomena

- 3.1 Sunlight: direct, scattered, reflected
- 3.2 Lightning

4. Electrical Discharge

- 4.1 Arcing
  - 4.1.1 Power Transformers
  - 4.1.2 Motors
  - 4.1.3 Electrical Devices
  - 4.1.4 Faulty Wiring
- 4.2 Flashlamps
- 4.3 Carbon Arcs

5. Nondestructive Investigative Devices (NDI)

- 5.1 Scattered X-rays
- 5.2 Scattered Secondary X-rays, UV, Direct, Reflected

6. Electromagnetic Waves

- 6.1 Communication Devices/Walkie Talkies/Radios/TV
- 6.2 Radar
- 6.3 IR Emission from security surveillance devices
- 6.4 Electric Power Switching
- 6.5 EMI from Electronic Equipment:
  - 6.5.1 Vehicle/Aircraft/Equipment Subsystems
  - 6.5.2 Electronic tools/equipment
  - 6.5.3 Microwave devices
  - 6.5.4 Weapon Systems

7. Personnel Items (very doubtfully near facility)

- 7.1 Lighted Cigarette, Cigar, Pipe
- 7.2 Matches (paper and wood)
- 7.3 Butane Lighter

8. Tools/Operations

    8.1 Welding Operations

        8.1.1 TIG
        8.1.2 Arc
        8.1.3 MIG

    8.2 Acetylene Welding and Cutting Operations

9. Hot Bodies, Blackbody Radiators

    9.1 Vehicle Engines, Manifolds, Exhausts, Radiators, Mufflers

    9.2 Ground Equipment Engines, Manifolds, Exhausts, Radiators, Mufflers from such equipment as:

        9.2.1 TTU 228/E Hydraulic Test Stand
        9.2.2 MA3 Air Conditioner
        9.2.3 AM 32A95 Gas Turbine Compressor
        9.2.4 MHU 83CE Truck Lift
        9.2.5 AM 32A60B Gas Turbine Generator
        9.2.6 MC2A Diesel Rotary Air Compressor
        9.2.7 H1 Gasoline Heater
        9.2.8 AF/M32T-1 Aircraft Tester
        9.2.9 MC2A Gasoline Air Compressor
        9.2.10 MC1A Compressor
        9.2.11 AM 32A-86 Generator Set

    9.3 Thermal Heating Blankets/Welding
    9.4 Radiation Electric Heaters (1.0 and 1.5 Kw with Fan)
    9.5 Radiation Kerosene Heater (70,000 BTU with Fan)
    9.6 Hot Lamps
    9.7 Hot Welding Materials

10. Security Personnel Weapons

    10.1 M-16 Rifles
    10.2 M-60 Machine Guns
    10.3 M-79 Grenade Launchers
    10.4 38 Caliber Pistols
    10.5 12-Gauge Shotguns

11. Fire/Explosive Events Associated with Vehicle and Ground Equipment Engine Wet Starts/Backfires

Figure 1. Typical Explosive Squib Valve Design and Operation

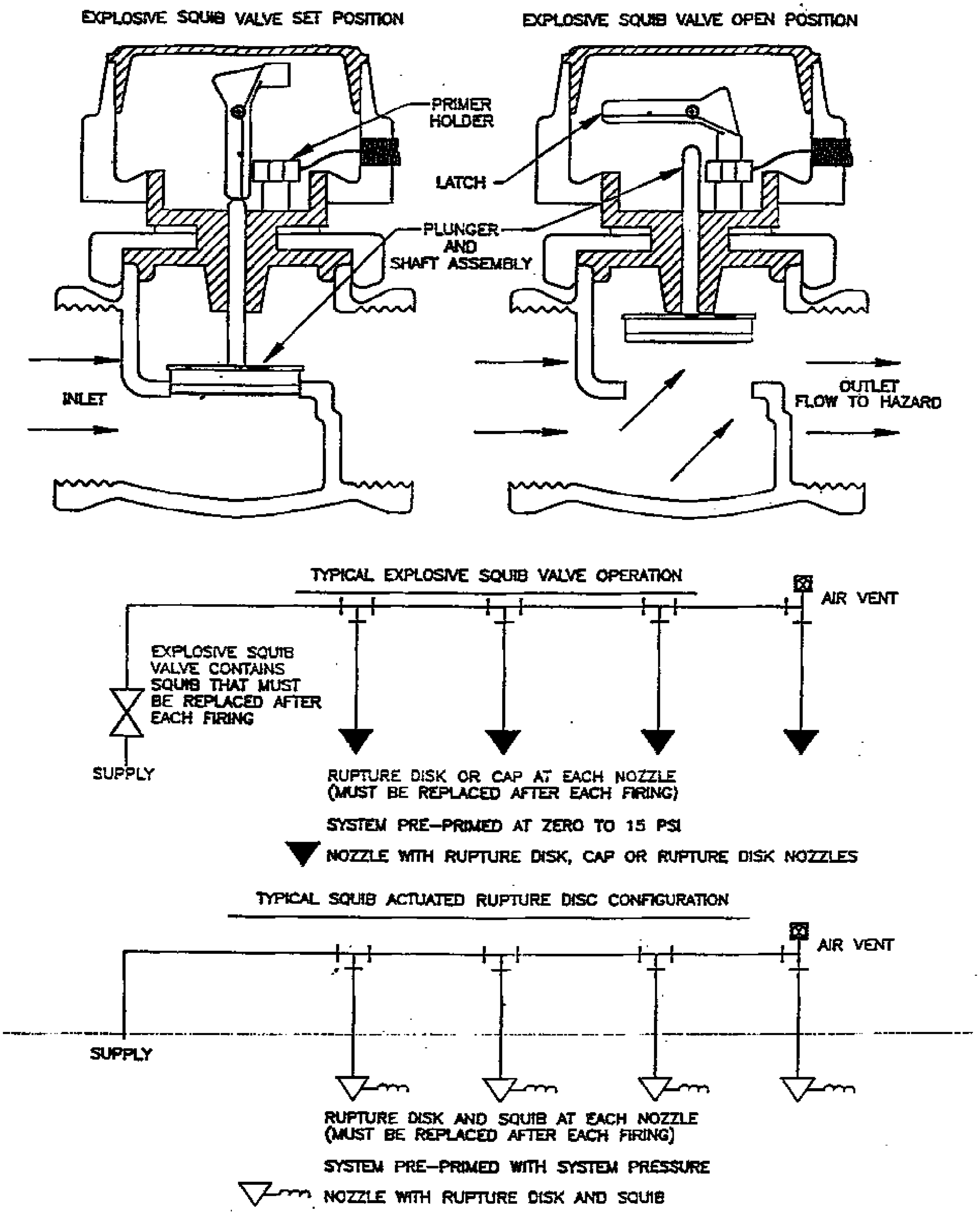

Figure 1. Typical Explosive Squib Valve Design and Operation

Figure 2. Pilot Valve Operations

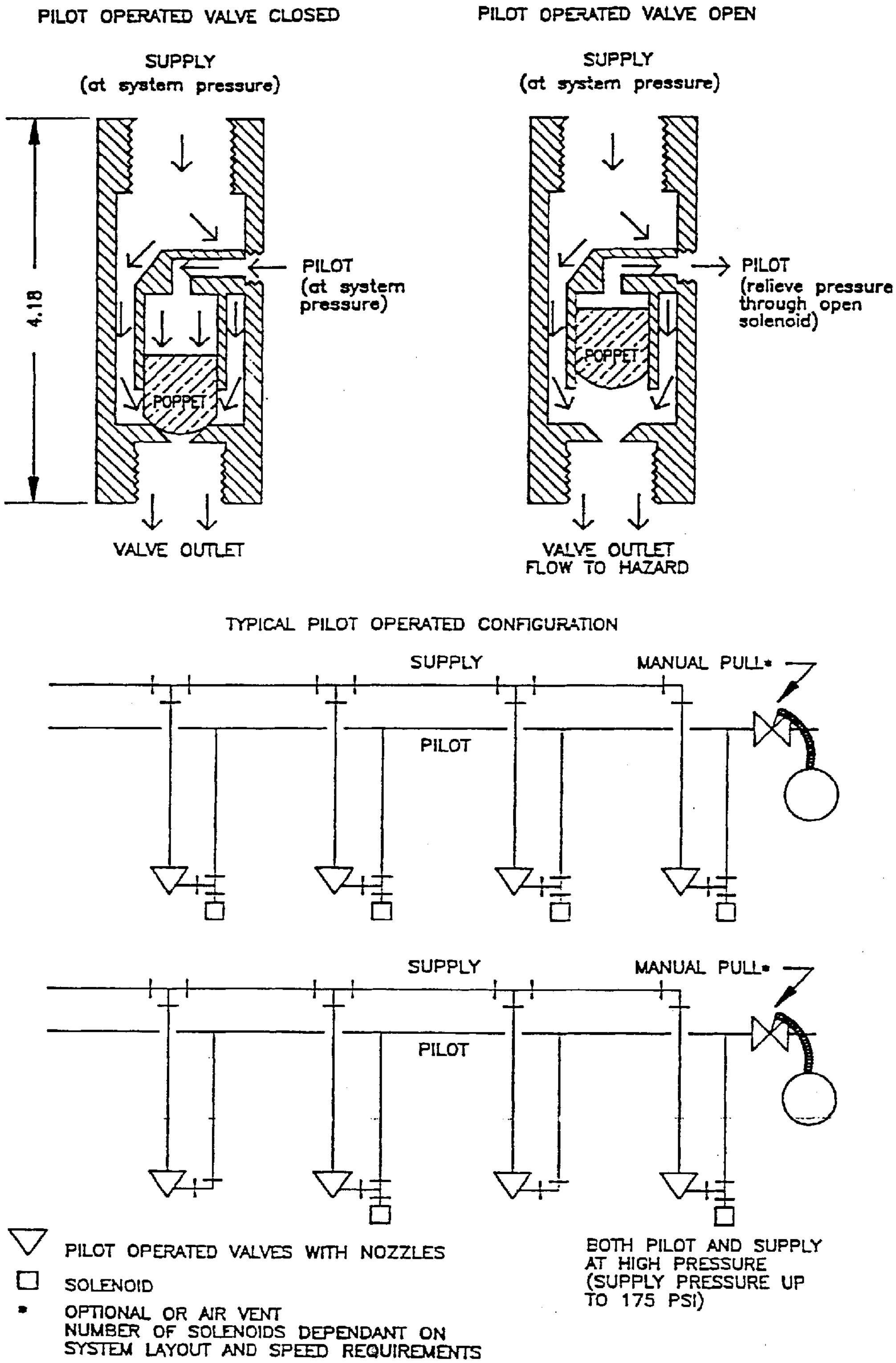

Figure 2. Pilot Valve Operations

Figure 3. Solid Propellant Pressurized Water System

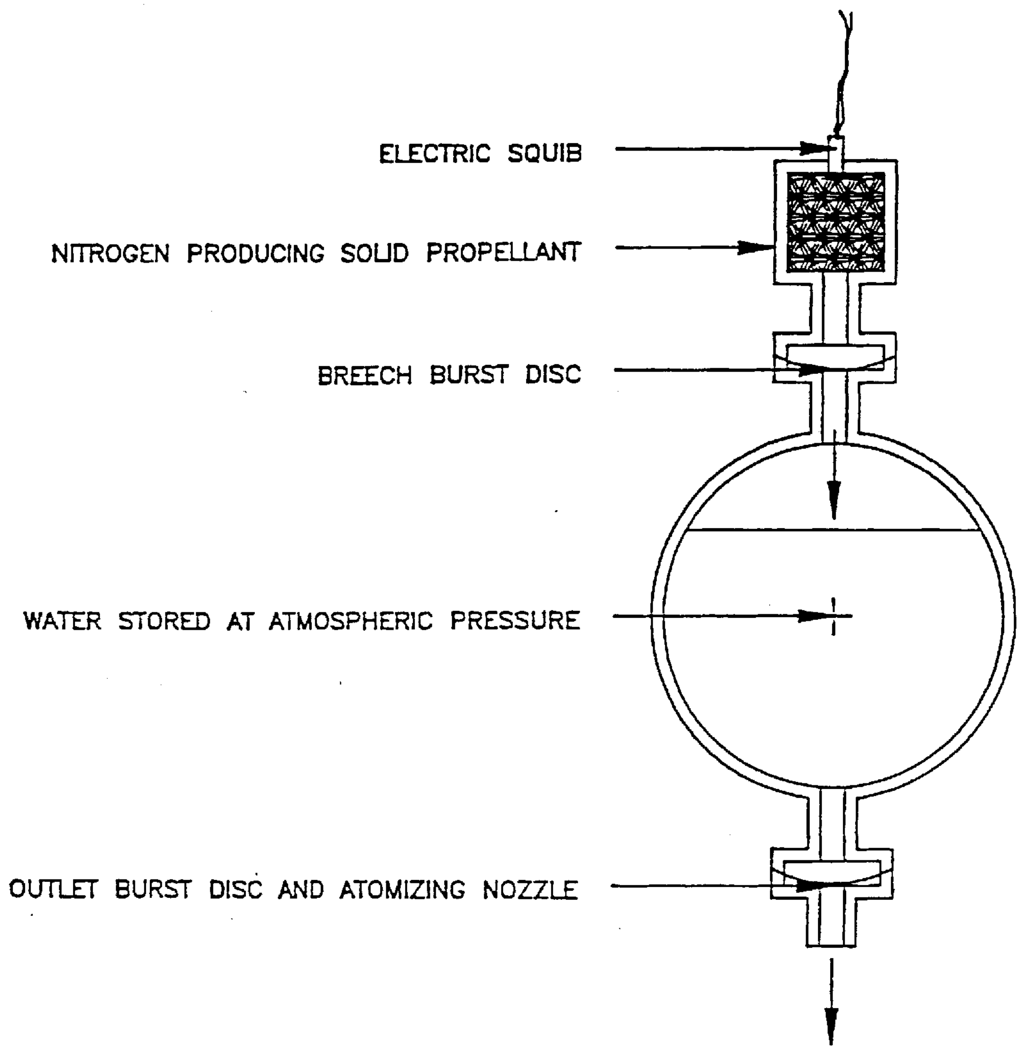

Figure 3. Solid Propellant Pressurized Water System

Figure 4. JP-$ Irradiance (185 NM UV Band)

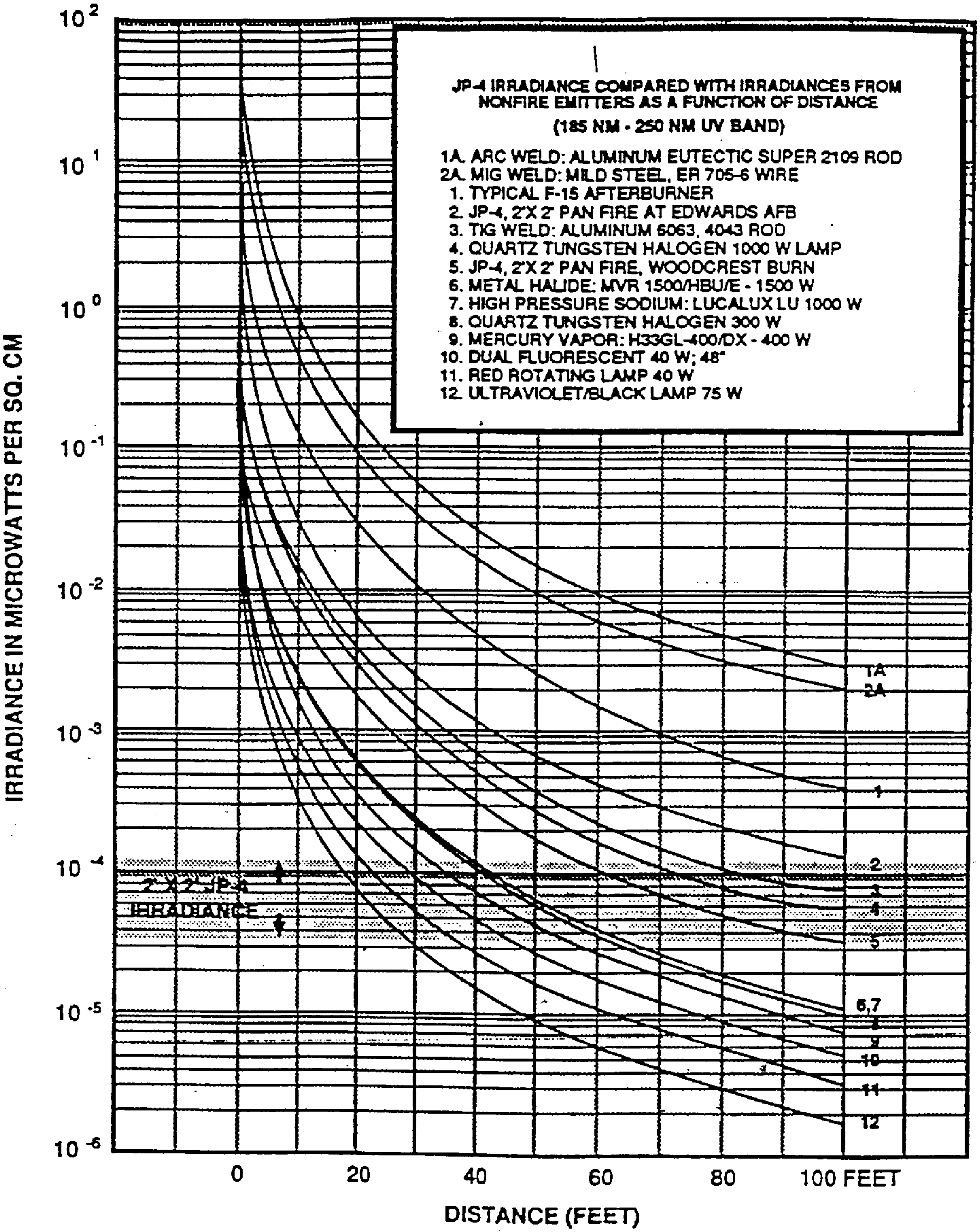

Figure 4. JP-4 Irradiance (185 NM - 250 NM UV Band)

Figure 5. JP-4 Irradiance (243 NM - 269 NM UV Band)

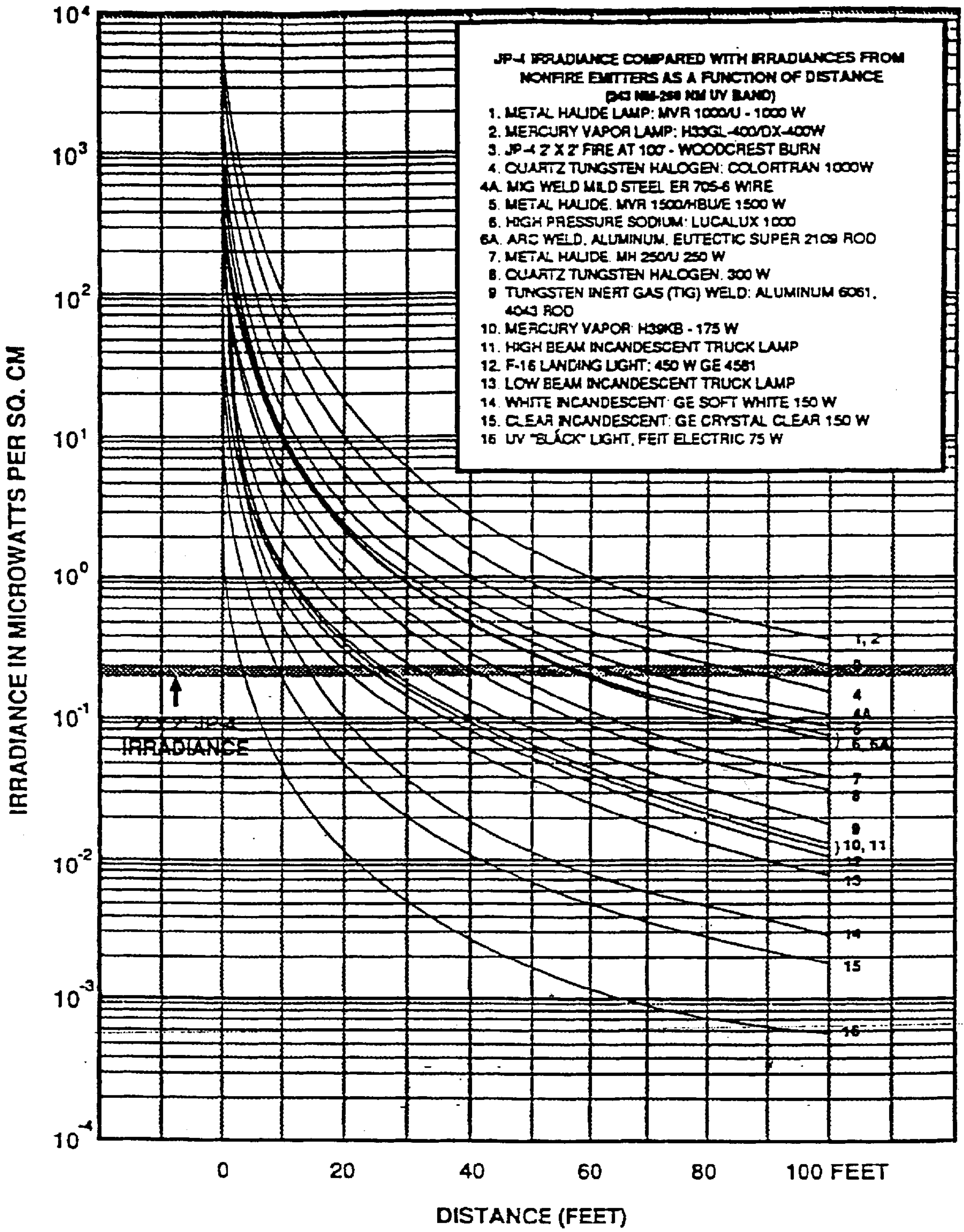

Figure 5. JP-4 Irradiance (243 NM - 269 NM UV Band)

Figure 6. JP-4 Irradiance (Infrared Band Centered at 4.37 uV)

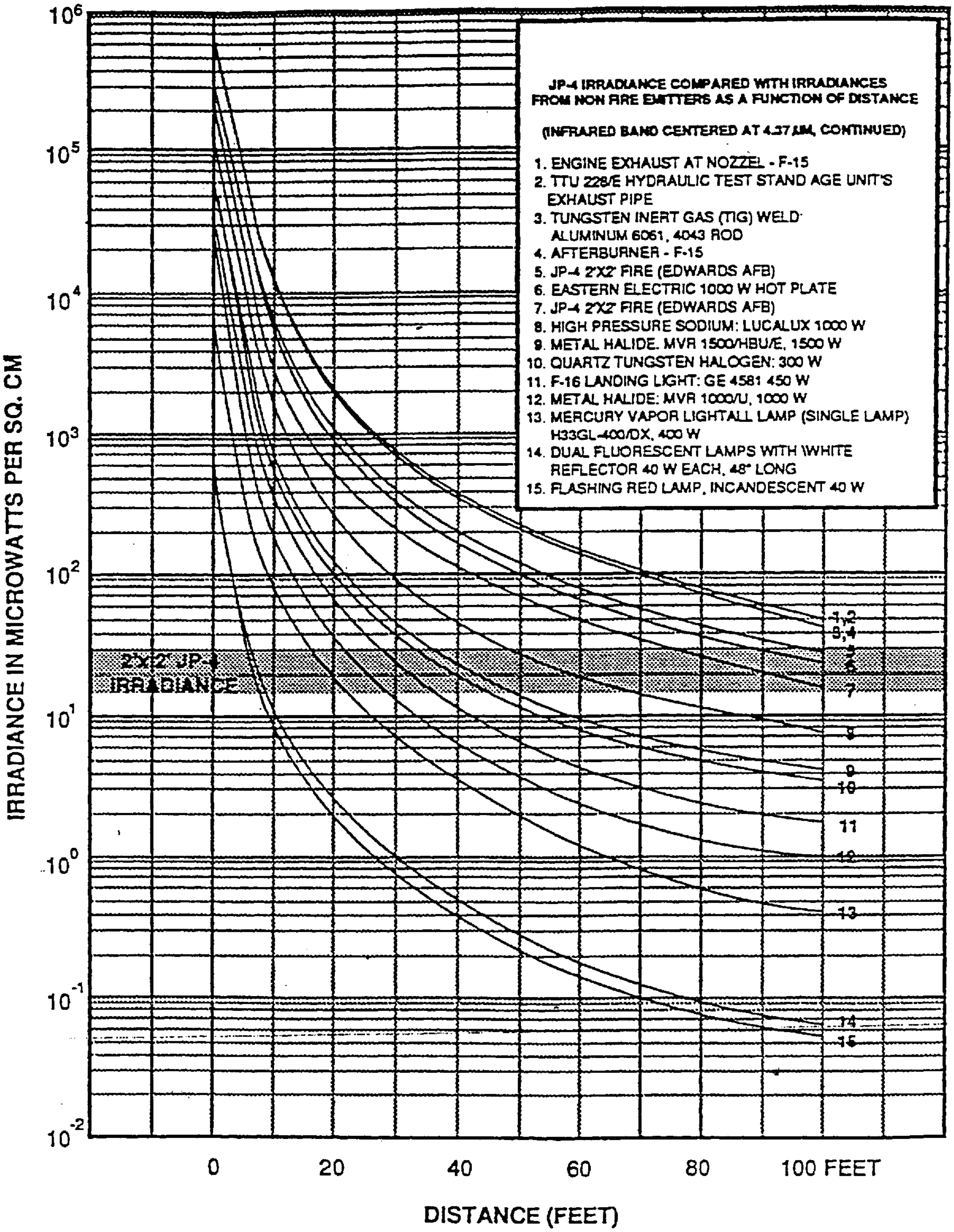

Figure 6. JP-4 Irradiance (Infrared Band Centered at 4.37 μV)